Appl. No. : 10/621,196
Filed : July 15, 2003

AMENDMENTS TO THE SPECIFICATION

In the Specification:

Please amend the specification as follows. Insertions appear as underlined text (e.g., insertions) while deletions appear as strikethrough text (e.g., ~~strikethrough~~). All previously amended claims appear as clean text.

Please replace the section entitled "Summary" with the following rewritten section:

The present invention solves these and other problems by providing a magnetic catheter guidance and control apparatus that requires less training and less skill that prior art systems. The magnetic catheter guidance system can rapidly advance and position the catheter, thus minimizing x-ray and contrast material exposure. Moreover, the magnetic system used in the magnetic catheter guidance system can be used to locate the catheter tip to provide location feedback to the operator and the control system.

Please amend paragraph [0007] as follows:

The implantation of cardiac pacemakers is often essential for the survival of patients with heart rhythm or electrical conduction disturbances. This procedure is performed by the implantation of a small electrode in the heart cavity wall (ventricle or atrium). The other end of the electrode is attached to an electronic device which is implanted under the chest skin and that generates stimulation pulses to **~~simulate~~** **stimulate** the heart rhythm. Similar devices apply electrical shock when life-threatening heart electrical disturbances are detected by the electrodes (e.g., an Automatic Implantable Cardiac Defibrillator (AICD)). These electrodes are placed through a vein by pushing and manipulating under x-ray. Many times, the manipulation to place the electrodes in a proper position is difficult and the results are sub-optimal due to anatomical variations.

Please amend paragraph [0013] as follows:

Percutaneous myocardium revascularization is a catheter-based procedure for promoting ~~angioneogensis~~ **angioneogenesis**. It involves advancing a laser catheter into the heart and performing the channeling from the heart inner aspect (endocardium). This approach is particularly applicable to patients who constitute a high surgical risk and who are beyond conventional catheter based therapy. Due to the accuracy required when positioning and fixating the laser catheter, this procedure does not appear to be implementable with currently available catheter technology.

Please amend paragraph [0016] as follows:

The present invention solves these and other problems by providing a magnetic catheter guidance and control apparatus that requires less training and less skill ~~that~~ **than** prior art systems. The magnetic catheter guidance system can rapidly advance and position the catheter, thus minimizing x-ray and contrast material exposure. Moreover, the magnetic system used in the magnetic catheter guidance system can be used to locate the catheter tip to provide location feedback to the operator and the control system.

Please amend paragraph [0042] as follows:

Figure 13C is a block diagram representing the electronics scheme of clustered electro-magnetic ~~eoils~~ **coils.**

Please amend paragraph [0043] as follows:

Figure 13D is a matrix representation of a ~~veetor~~ **vector.**

Please amend paragraph [0044] as follows:

Figure 13E is a representation of the characteristic ~~matrix~~ **matrix.**

Please amend paragraph [0045] as follows:

Figure 13F is a representation of the Inverse characteristic ~~matrix~~ **matrix.**

Please amend paragraph [0046] as follows:

Figure 13G is a representation of the product of the characteristic matrix with its Inverse ~~matrix~~ **matrix.**

Please amend paragraph [0047] as follows:

Figure 13H is a logical flow diagram of ~~fig. 13G~~ **FIG. 13G.**

Please amend paragraph [0073] as follows:

Referring to ~~FIG. 1B~~ **FIG. 1C**, the power supply and control system 392 includes: a Ground Fault Interrupter (GFI) 1; an uninterruptible power supply (UPS) 300; a supervisory unit (SU) 301; individual DC power supplies XPS 16, YPS 17, and ZPS 18 that provide power to the X Axis Controller And Amplifier (XCA) 305, the Y-axis Controller And Amplifier (YCA) 310, and the Z-axis Controller and Amplifier (ZCA) 315, respectively; and a DC system power supply (SPS) 19 that provides the DC power needed to operate other digital and analog circuitry of the GCI apparatus 501. These components and their functional relationships are depicted in greater detail in FIG. 2.

Please amend paragraph [0080] as follows:

With references to ~~Figs. 1B~~ **FIGS 1C** and 3, System Controller (SC) 302 controls the power up – power down sequence in an orderly fashion and alerts the operator to the system status and any required corrective action via Communications Controller (CC) 320, Computer 324, and monitor 325. In addition, System Controller (SC) 302 coordinates the operation of X Axis Controller and Amplifier (XCA) 305, Y-Axis Controller and Amplifier (YCA) 310, and Z Axis Controller and Amplifier (ZCA) 315. Additionally, System Controller (SC) 302 Communicates with Virtual Tip/Calibration Fixture Controller (VT/CFC) 321 and Communication Controller (CC) 320 via system bus 328.

Please amend paragraph [0084] as follows:

The Z-Axis Power Supply (ZPS) 18 provides DC power to the Z-Axis Controller and Amplifier (ZCA) 315 for energizing the electromagnets (EM) 132Z and 138(Z) that are located

outside the patient's body. ZCA 315 monitors the sensor arrays of the Z-axis that include the following components: temperature sensor (TS) arrays 316, ~~318~~ 319, and magnetic field sensor arrays 317, 319. Magnetic field sensor arrays 317 and ~~319~~ 318 measure the magnetic flux in the Z axis. Temperature sensor (TS) arrays 316 and ~~318~~ 319 measure the temperature of magnetic field sensor arrays 317 and ~~319~~ 318 , so that Z Axis Controller and Amplifier (ZCA) 315 can apply temperature compensation factors to the magnetic field sensor outputs. The sensory outputs of these arrays 316, 317, 318, 319 provide feedback to the servo system controlled by ZCA 315 concerning the position of the present catheter tip 377 with reference to the Z-axis. As it will become apparent from the present description, these electromagnets 132Z and 138Z affect the position of the present catheter tip 377 inside the patient's body 390 in the Z-axis.

Please amend paragraph [0092] as follows:

During the calibration mode, System Controller (SC) 302 exercises Calibration Fixture (CF) ~~312~~ 321 via Virtual Tip/Calibration Fixture controller (VT/CFC) 303 and correlates the position data from X-axis Controller and Amplifier (XCA) 305, Y-axis Controller and Amplifier (YCA) 310, and Z-axis Controller and Amplifier (ZCA) 305 with Calibration Fixture (CF) 321 encoders 64C, 66C, 68C, 70C, and 72C.

Please amend paragraph [0095] as follows:

Referring to FIG. 5, the electronic circuitry function of the VT assembly 304 is as follows. A decode logic 101 responds to address and control bits originating from Virtual Tip/Calibration Fixture controller (VT/CFC) 303 (~~FIG.3~~ FIG. 4), enabling data buffer 51 and setting its direction for transferring data. Step latches 52 and 53 store incoming data sent from the VT/CFC 303 to be presented to stepper drivers 54, 56, 58, 60 and 62 when strobed by decode logic 101. Stepper motors 55, 57, 59, 61, and 63 respond to the stepper driver outputs to provide tactile feedback to the operator. The stepper motors 55, 57, 59, 61, and 63 create tactile feedback by producing resistance in the appropriate axial or angular coordinates as follows: stepper motor 55 in the X-axis 400; stepper motor 57 in the Y-axis 401, stepper motor 59 in the Z-axis 402; stepper motor 61 in the angular direction of 0; and stepper motor 63 in the angular direction of EL.

Please amend paragraph [0098] as follows:

First, the method by which XCA 305 monitors the sensory data from the MFS arrays 307 and 308 and temperature sensor arrays 306 and 309 will be explained. Magnetic field sensors sensor array 307 includes magnetic field sensors ~~113x, 114x, 115x, and 116x~~ 113X, 114X, 115X, AND 116X. Magnetic field sensors sensor array 308 includes magnetic field sensors ~~117x, 118x, 119x, and 120x~~ 117X, 118X, 119X, AND 120X. Temperature sensor array 306 includes temperature sensors ~~122x, 123x, 124x, and 125x~~ 122X, 123X, 124X, AND 125X. Temperature sensor array 309 includes temperature sensors ~~126x, 127x, 128x, and 129x~~ 126X, 127X, 128X, 129X. The physical positions of these sensors and relations to one another are described in conjunction with FIG. 13. Microcontroller ~~102x~~ 102X executes a mathematical procedure that is described in conjunction with Figs. 18, 18A, 18B and 18C, that calculates positional data based on input from the sensor arrays 307 and 308. Input and output data is stored in Random Access Memory (RAM) ~~103x~~ 103X during system operation. Non Volatile Memory (NVM) ~~105x~~ 105X stores data such as temperature compensation parameters which are used in combination with measured temperature sensor array 306 and 309 data to make necessary corrections to data from the magnetic field sensors 113X, 114X, 115X, 116X, 117X, 118X, 119X, and 120X.

The collecting of sensory data is initiated by decode logic 160x in conjunction with address latch ~~111x~~ 111X that allows microcontroller ~~12x~~ 102X to set the input channel of analog multiplexer ~~112x~~ 112X. Similarly, decode logic ~~106x~~ 106X in conjunction with address latch ~~109x~~ 109X allows microcontroller ~~102x~~ 102X to set the gain of programmable gain amplifier ~~110x~~ 110X in order to compensate for variations in signal strength from the sensor arrays 307, 308, 306, and 309. Microcontroller ~~102x~~ 102X strobes sample and hold circuit ~~108x~~ 108X via decode logic ~~106x~~ 106X, so that microcontroller ~~102x~~ 102X is able to perform other functions while periodically sampling the data temporarily stored in sample and hold circuit 108X. The output of sample and hold circuit ~~108x~~ 108X is thus a "snapshot" of the signal to be measured.

Please amend paragraph [0099] as follows:

Analog-to-Digital Converter (ADC) ~~**107x**~~ **107X** is issued a "convert" command by microcontroller ~~**102x**~~ **102X** via decode logic ~~**106x**~~ **106X** to convert the data from the position

sensors 307 and 308 from analog to digital, so that the digital system can interpret the data. When the conversion is complete, analog to digital converter ~~107x~~ 107X interrupts microcontroller ~~102x~~ 102X via decode logic ~~106x~~ 106X and the digital representation of the measured signal is input by microcontroller ~~102x~~ 102X. It is by this method that the magnetic field sensors ~~113x~~ 113X, ~~114x~~ 114X, ~~115x~~ 115X, ~~116x~~ 116X, ~~117x~~ 117X, ~~118x~~ 118X, ~~119x~~ 119X, and ~~120x~~ 120X as well as the temperature sensors ~~122x~~ 122X, ~~123x~~ 123X, ~~124x~~ 124X, ~~125x~~ 125X, ~~126x~~ 126X, ~~127x~~ 127X, ~~128x~~ 128X, and ~~129x~~ 129X are monitored. Similarly, the voltage drop across the shunts 131X and 137X is measured to determine the current flow through the electromagnets 132X and 138X.

Please amend paragraph [0100] as follows:

Still referring to FIG. 7, current source ~~121x~~ 121X provides the control current to bias the magnetic field sensors 113X, 114X, 115X, 116X. 117X, 118X, 119X, and 120X. since they operate best in a constant current mode and require stability for reliable sensing. Temperature sensor bias supply ~~130x~~ 130X supplies the voltage for the temperature sensors 122X, 123X, 124X, 125X, 126X, 127X, 128X, 129X.

Please amend paragraph [0101] as follows:

The method by which XCA 305 generates commands to control the movement of the present catheter tip 377 in the X-axis will now be explained. Microcontroller 102X receives data from VT/CFC 303 and other system components via system bus 328 to use in generating commands that will control the movement. Microcontroller ~~102x~~ 102X in conjunction with decode logic ~~106x~~ 106X controls modulators ~~144x~~ 144X and ~~146x~~ 146X to provide the correct move signal and command. Preamplifiers ~~143x~~ 143X, and ~~145x~~ 145X amplify the modulators outputs and drive final amplifiers ~~135x~~ 135X, ~~136x~~ 136X, ~~141x~~ 141X, and ~~142x~~ 142X. Diodes ~~133x~~ 133X, ~~134x~~ 134X, ~~139x~~ 139X, and ~~140x~~ 140X protect the final amplifiers from a surge of back electromotive force due to the inductive nature of the electromagnet coils 132X and 138X.

Please amend paragraph [0102] as follows:

Electromagnet coils ~~132x~~ 132X and ~~138x~~ 138X produce a magnetic field that affects the position of the present catheter tip in the X-Axis.

Microcontroller 102X communicates with VT/CFC 303 and other system components via system bus 328 by setting the appropriate address and control bits to decode logic ~~106x~~ 106X, which enables address buffer ~~148x~~ 148X and data buffer ~~147x~~ 147X.

Please amend paragraph [0103] as follows:

Non Volatile Memory (NVM) ~~105x~~ 105X also stores calibration data to be used during calibration operations in conjunction with the calibration fixture 321 and VT/CFC 303. These operations and the source of the calibration data will be described later in conjunction with FIG. 23. Further, Non Volatile Memory (NVM) ~~105x~~ 105X stores error codes to be used during power down operations controlled by the System Controls (SC) 302.

Please amend paragraph [0105] as follows:

First, the method by which YCA 310 monitors the sensory data from MFS arrays 312 and 313 and temperature sensor arrays 311 and 314 will first be explained. Magnetic field sensor array 312 includes magnetic field sensors ~~113y~~ 113Y, ~~114y~~ 114Y, ~~115y~~ 115Y and ~~116y~~ 116Y. Magnetic field sensor array 313 includes magnetic field sensors ~~117y~~ 117Y, ~~118y~~ 118Y, ~~119y~~ 119Y, and ~~120y~~ 120Y. Temperature sensor array 311 includes temperature sensors ~~122y~~ 122Y, ~~123y~~ 123Y, ~~124y~~ 124Y, and ~~125y~~ 125Y. Temperature sensor array 314 includes temperature sensors ~~126y~~ 126Y, ~~127y~~ 127Y, ~~128y~~ 128Y, and ~~129y~~ 129Y. The physical positions of these sensors and relations to one another are described in conjunction with FIG. 13.

Please amend paragraph [0106] as follows:

Microcontroller ~~102y~~ <u>102Y</u> executes a mathematical procedure, that described in conjunction with Figs. 18, 18A, 18B and 18C, that calculates positional data based on input from the sensor arrays 312 and 313. Input and output data is stored in Random Access Memory (RAM) 103y <u>103Y</u> during system operation. Non Volatile Memory (NVM) ~~105y~~ <u>105Y</u> stores data such as temperature compensation parameters which are used in combination with measured temperature sensor array 311 and 314 data to make necessary corrections to data from the magnetic field sensors 113Y, 114Y, 115Y, 116Y, 117Y, 118Y, 119Y, and 120Y.

The collecting of sensory data is initiated by decode logic ~~106y~~ <u>106Y</u> in conjunction with address latch ~~111y~~ <u>111Y</u>, which allows microcontroller ~~102y~~ <u>102Y</u> to set the input channel of analog multiplexer ~~112y~~ <u>112Y</u>. Similarly, decode logic ~~106y~~ <u>106Y</u> in conjunction with address latch ~~109y~~ <u>109Y</u> allows microcontroller ~~102y~~ <u>102Y</u> to set the gain of programmable gain amplifier ~~110y~~ <u>110Y</u>, in order to compensate for variations in signal strength from the sensor arrays 311, 312, 313, and 314. Microcontroller ~~102y~~ <u>102Y</u> strobes sample and hold circuit ~~108y~~ <u>108Y</u> via decode logic ~~106y~~ <u>106Y</u>, to allow microcontroller ~~102y~~ <u>102Y</u> to perform other functions while periodically sampling the data temporarily stored in sample and hold circuit 108Y. The output of sample and hold circuit ~~108y~~ <u>108Y</u> is thus a "snapshot" of the signal to be measured.

Please amend paragraph [0107] as follows:

Analog to Digital Converter (ADC) ~~107y~~ <u>107Y</u> is issued a convert command by microcontroller ~~102y~~ <u>102Y</u> via decode logic ~~106y~~ <u>106Y</u> to convert the data from the position sensors 312 and 313 from analog to digital, so that the digital system can interpret the data. When the conversion is complete, analog to digital converter ~~107y~~ <u>107Y</u> interrupts microcontroller ~~102y~~ <u>102Y</u> via decode logic ~~106y~~ <u>106Y</u> and the digital representation of the measured signal is input by microcontroller ~~102y~~ <u>102Y</u>. It is by this method that the magnetic field sensors ~~113y~~ <u>113Y</u>, ~~114y~~ <u>114Y</u>, ~~115y~~ <u>115Y</u>, ~~116y~~ <u>116Y</u>, ~~117y~~ <u>117Y</u>, ~~118y~~ <u>118Y</u>, ~~119y~~ <u>119Y</u>, and ~~120y~~ <u>120Y</u> as well as the temperature sensors ~~122y~~ <u>122Y</u>, ~~123y~~ <u>123Y</u>, ~~124y~~ <u>124Y</u>, ~~125y~~ <u>125Y</u>, ~~126y~~ <u>126Y</u>, ~~127y~~ <u>127Y</u>, ~~128y~~ <u>128Y</u>, and ~~129y~~ <u>129Y</u> are monitored. Similarly, the voltage drop across the

shunts 131Y and 137Y is measured to determine the current flow through the electromagnets 132Y and 138Y.

Please amend paragraph [0108] as follows:

Still referring to FIG. 8, current source ~~121y~~ **121Y** provides the control current to bias the magnetic field sensors 113Y, 114Y 115Y, 116Y, 117Y, 118Y, 119Y, and 120Y, since they operate best in a constant current mode and require stability for reliable sensing. Temperature sensor bias supply ~~130y~~ **130Y** supplies the voltage for the temperature sensors 122Y, 123Y, 124Y, 125Y, 126Y. 127Y, 128Y, and 129Y.

Please amend paragraph [0109] as follows:

The method by which YCA 310 generates commands that will control the movement of the present catheter tip in the Y-Axis will now be explained. Microcontroller 102Y receives data from VT/CFC 303 and other system components via system bus 328 to use in generating commands that will control the movement of the present catheter tip in the Y-axis will now be explained. Microcontroller ~~102y~~ **102Y** in conjunction with decode logic ~~106y~~ **106Y** controls modulators ~~144y~~ **144Y** and ~~146y~~ **146Y** to provide the correct move signal and command. Preamplifiers ~~143y~~ **149Y**, and ~~145y~~ **145Y** amplify the modulators outputs and drive final amplifiers ~~135y~~ **135Y**, ~~136y~~ **136Y**, ~~141y~~ **141Y**, and ~~142y~~ **142Y**. Diodes ~~133y~~ **133Y**, ~~134y~~ **134Y**, ~~139y~~ **139Y**, and ~~140y~~ **140Y** protect the final amplifiers from a surge of back electromotive force due to the inductive nature of the electromagnet coils 132Y and 138Y. Electromagnet coils 132y and 138y produce the magnetic field which will affect the position of the present catheter tip 377 in the Y-Axis.

Please amend paragraph [0110] as follows:

Microcontroller 102Y communicates with VT/CFC 303 and other system components via system bus 328 by setting the appropriate address and control bits to decode logic ~~106y~~ 106Y, which enables address buffer ~~148y~~ 148Y and data buffer ~~147y~~ 147Y.

Please amend paragraph [0111] as follows:

Non Volatile Memory (NVM) ~~105y~~ 105Y also stores calibration data to be used during calibration operations in conjunction with the calibration fixture 321 and VT/CFC 303. These operations and the source of the calibration data will be described later in conjunction with FIG. 23. Further, Non Volatile Memory (NVM) ~~105y~~ 105Y stores error codes to be used during power down operations controlled by the System Controls (SC) 302.

Please amend paragraph [0113] as follows:

First, the method by which ZCA 315 monitors the sensory data from MFS arrays 317 and 318 and temperature sensor arrays 316 and 319 will first be explained. Magnetic field sensor array 317 includes magnetic field sensors ~~113z~~ 113Z, ~~114z~~ 114Z, ~~115z~~ 115Z and ~~116z~~ 116Z. Magnetic field sensor array 318 includes magnetic field sensors ~~117z~~ 117Z, ~~118z~~ 118Z, ~~119z~~ 119Z, and ~~120z~~ 120Z. Temperature sensor array 316 includes temperature sensors ~~122z~~ 122Z, ~~123z~~ 123Z, ~~124z~~ 124Z, and ~~125z~~ 125Z. Temperature sensor array 319 includes temperature sensors ~~126z~~ 126Z, ~~127z~~ 127Z, ~~128z~~ 128Z, and ~~129z~~ 129Z. The physical positions of these sensors and relation to one another are described in conjunction with FIG 13.

Please amend paragraph [0114] as follows:

Microcontroller ~~102z~~ 102Z executes a mathematical procedure that is described in conjunction with Figs. 18, 18A, 18B and 18C, and that calculates positional data based on input from the sensor arrays 317 and 318. Input and output data is stored in Random Access Memory (RAM) ~~103z~~ 103Z during system operation. Non Volatile Memory (NVM) ~~105z~~ 105Z stores data such as temperature compensation parameters that are used in combination with measured

data from the temperature sensor arrays 316 and 319, to make necessary corrections to the data from the magnetic field sensors 113Z, 114Z, 115Z, 116Z, 117Z, 118Z, 119Z, and 120Z.

Please amend paragraph [0115] as follows:

The collecting of sensory data is initiated by decode logic ~~106z~~ 106Z in conjunction with address latch ~~111z~~ 111Z that allows microcontroller ~~102z~~ 102Z to set the input channel of analog multiplexer ~~112z~~ 112Z. Similarly, decode logic ~~106z~~ 106Z in conjunction with address latch ~~109z~~ 109Z allows microcontroller ~~102z~~ 102Z to set the gain of programmable gain amplifier ~~110z~~ 110Z, in order to compensate for variations in signal strength from the sensor arrays 316, 317, 318, and 319.

Please amend paragraph [0116] as follows:

Microcontroller ~~102z~~ 102Z strobes sample and hold circuit ~~108z~~ 108Z via decode logic ~~106z~~ 106Z, to allow microcontroller ~~102z~~ 102Z to perform other functions while periodically sampling the data temporarily stored in sample and hold circuit 108Z. The output of sample and hold circuit ~~108z~~ 108Z is thus a "snapshot" of the signal to be measured. Analog to Digital Converter (ADC) ~~107z~~ 107Z is issued a convert command by microcontroller ~~102z~~ 102Z via decode logic ~~106z~~ 106Z, to convert the data from the position sensors 317 and 318 from analog to digital, so that the digital system can interpret the data. When the conversion is complete, analog to digital converter ~~107z~~ 107Z interrupts microcontroller ~~102z~~ 102Z via decode logic ~~106z~~ 106z and the digital representation of the measured signal is input by microcontroller ~~102z~~ 102Z. It is by this method that the magnetic field sensors ~~113z~~ 113Z, ~~114z~~ 114Z, ~~115z~~ 115Z, ~~116z~~ 116Z, ~~117z~~ 117Z, ~~118z~~ 118Z, ~~119z~~ 119Z, and ~~120z~~ 120Z as well as the temperature sensors ~~122z~~ 122Z, ~~123z~~ 123Z, ~~124z~~ 124Z, ~~125z~~ 125Z, ~~126z~~ 126Z, ~~127z~~ 127Z, ~~128z~~ 128Z, and ~~129z~~ 129Z are monitored. Similarly, the voltage drop across the shunts 131Z and 137Z is measured to determine the current flow through the electromagnets 132Z and 138Z.

Please amend paragraph [0117] as follows:

Still referring to FIG. 9, current source ~~121z~~ 121Z provides the control current to bias the magnetic field sensors 113Z, 114Z, 115Z, 116Z, 117Z, 118Z, 119Z, and 120Z since they operate best in a constant current mode, and require stability for reliable sensing. Temperature sensor bias supply ~~130z~~ 130Z supplies the voltage for the temperature sensors 112Z, 123Z, 124Z 125Z, 126Z, 127Z, 128Z, and 129Z.

Please amend paragraph [0118] as follows:

The method by which ZCA 315 generates commands that will control the movement of the present catheter tip in the Z-axis will now be explained. Microcontroller 102Z receives data from VT/CFC 303 and other system components via system bus 328, to use in generating commands that will control the movement of the present catheter tip in the Z-axis will now be explained. Microcontroller ~~102z~~ 102Z in conjunction with decode logic ~~106z~~ 106Z controls modulators ~~144z~~ 144Z and ~~146z~~ 146Z to provide the correct move signal and command. Preamplifiers ~~143z~~ 143Z, and ~~145z~~ 145Z amplify the modulators outputs and drive final amplifiers ~~135z~~ 135Z, ~~136z~~ 136Z, ~~141z~~ 141Z, and ~~142z~~ 142Z. Diodes ~~133z~~ 133Z, ~~134z~~ 134Z, ~~139z~~ 139Z, and ~~140z~~ 140Z protect the final amplifiers from a surge of back electromotive force due to the inductive nature of the electromagnet coils 132Z and 138Z. Electromagnet coils ~~132z~~ 132Z and ~~138z~~ 138Z produce the magnetic field which will affect the position of the present catheter tip in the Z-axis.

Please amend paragraph [0119] as follows:

Microcontroller 102Z communicates with VT/CFC 303 and other system components via system bus 328 by setting the appropriate address and control bits to decode logic 106z, which enables address buffer ~~148z~~ 148Z and data buffer ~~147z~~ 147Z.

Please amend paragraph [0120] as follows:

Non Volatile Memory (NVM) ~~105z~~ 105Z also stores calibration data to be used during calibration operations in conjunction with the calibration fixture 321 and VT/CFC 303. These operations and the source of the calibration data will be described later in conjunction with FIG. 23. Further, Non Volatile Memory (NVM) ~~105z~~ 105Z stores error codes to be used during power down operations controlled by the System Controls (SC) 302.

Please amend paragraph [0124] as follows:

The circuitry of FIG. 11 operates as follows: A decode logic 101c **101C** responds to address and control bits originating from VT/CFC 303 and enables data buffer ~~51c~~ 51C and sets its direction. Step latches ~~52c~~ 52C and ~~53c~~ 53C store data to be presented to stepper drivers ~~54c~~ 54C, ~~56c~~ 56C, ~~58c~~ 58C, ~~60c~~ 60C, and ~~62c~~ 62C when strobed by decode logic ~~101c~~ 101C. Stepper motors ~~55c~~ 55C, ~~57c~~ 57C, ~~59c~~ 59C, ~~61c~~ 61C, and ~~63c~~ 63C respond to the stepper drive outputs to manipulate the magnetic calibration tip in the 5 axes. Absolute encoders ~~64c~~ 64C, ~~66c~~ 66C, ~~68c~~ 68C, ~~70c~~ 70C, and ~~72c~~ 72C are mechanically coupled to the corresponding stepper motors and provide position feedback to the VT/CFC 303. The outputs of the encoders 64C, 66C, 68C, 70C and 72C are buffered by data buffers ~~65c~~ 65C, ~~67c~~ 67C, ~~69c~~ 69C, ~~71c~~ 71C and ~~73c~~ 73C to temporarily store and transfer the data. Limit "switches" ~~74c~~ 74C, ~~75c~~ 75C, ~~76c~~ 76C, ~~77c~~ 77C, ~~78c~~ 78C, and ~~79c~~ 79C flag the ends of the three linear axes X, Y and Z. "Switches" ~~80c~~ 80C and ~~81c~~ 81C indicate when θ and EL are at zero position. Limit latch ~~82c~~ 82C stores this data when strobed by decode logic ~~101c~~ 101C.

Please amend paragraph [0125] as follows:

FIG. 13 Illustrates the polar configuration 374 of the electromagnets 132X, 132Y, 132Z, 138Z, 138Y, and ~~138Z~~ 138X, the magnetic field sensors and temperature sensor pairs 350, 351, 352, 353, 354, 355, 356, 357, 358, 359, 360, 361, 362, 363, 364, 365, 366, 367, 368, 369, 370, 371, 372, and 373. The electromagnets ~~132x~~ 132X, ~~132y~~ 132Y, ~~132z~~ 132Z are arranged in three orthogonal axes X, Y, Z, or as shown in FIGS. 13A and 13B.

Please amend paragraph [0126] as follows:

FIG. 13A and FIG. 13B illustrate a polar clustered configuration poles where the operating table 389 and electromagnets 901, 902, and 903 are configured relative to 904, 905, and 906, as approximately shown and mounted by the use of support assembly 391 configured as a C-Arm to compliment and close the magnetic field circuit. The polar configuration 374 is further expressed as a non-symmetrical distribution of the polar arrangement where electromagnet 901 and its counterpart 903 are rotated to provide a lobed electromagnetic field. This arrangement further optimizes the magnetic circuit and provides for free access for the physician and the patient while the Z axis electromagnets 905 and 906 do not obstruct the available access space as approximately shown by FIG. 13 and ~~fig.~~ FIG. 16. Furthermore FIG. 13 and FIG. 13A and FIG. 13B compliment each other and are an alternative to the bi-plane ring shown in FIG. 16, FIG. 16A, FIG. 16B and FIG. 16C. Both arrangements represent a possible approach provided in accommodating the imaging technology modalities such as x-ray, Cat-Scan, Pet-Scan and Ultrasound, while FIG. 16 provides for the GCI apparatus 501 as a natural access for a fluoroscopic imaging on a bi-plane arrangement. FIG. 13, 13A and 13B enable geometry with a bore of approximately 25 inches which is capable of incorporating a computer tomography apparatus and/or the modality noted above. Further embodiment of using the geometrical arrangement noted in FIG. 13A and 13B is expressed in the ensuing descriptions of FIG. 13C, 13D, 13E, 13F, 13G and 13H. The two competing architectures shown in FIG. 16, 16A, 16B 16C and FIG. 13A, 13B, provide for advantages and disadvantages in mounting the operating interface equipment 500, surgical medical equipment 502, and the GCI apparatus 501. Further FIG. 13A and 13B illustrate an alternative arrangement of the coils attached to the C-arm, 391, and table 389. In this arrangement coils 901 through 906 are shown in a cluster configuration. This geometry diverts from the intuitive orthogonal structure of coils commonly used when generating vectors or vector gradients with the aide of electromagnetic coils. FIG. 13B further illustrates the six coils, 901 through 906, configured in a flower-like structure, or a cluster. Three of the coils are mounted at the top of the C-arm 391, and three at the bottom. The three coils forming the upper cluster are further shifted by 120 degrees relative to each other, as are the bottom three coils. In addition, the coils of the cluster at the top of the C-arm are also tilted downward somewhat, at an angle of 15 to 20 degrees, as are the coils of the cluster at the

bottom of the C-arm tilted upward, as shown in FIG. 13B. The entire cluster at the top of the C-arm is rotated with respect to the bottom cluster by an angle of 60 degrees.

Please amend paragraph [0128] as follows:

FIGS. 13C, 13D, 13E, 13F, 13G and 13H, show an alternative architecture of the GCI apparatus 501 whereby the polar configuration noted in FIGS. 16. 16A, 16B, and 16C, is altered to accommodate the cluster configuration of the electro-magnet circuit as shown in FIG. 13A and 13B. ~~FIG. 13B~~ FIG. 13C is a simplified block diagram of the electrical scheme of the various components of the system. The system comprises a power supply, ~~910~~ 916, a joystick, 900, feeding three channels, X, Y, and Z, where the three signals taken together form a matrix **V**, 923, shown in FIG. 13D, comprising elements Vj_x, Vj_y, and Vj_z. This arrangement is further explained in FIG. 13D, 13E, 13F, 13G and 13H. FIG. 13C, the X-axis channel, comprises an Op-Amp 911, a current amplifier 910, and coil pair 901, 903. The Y-axis channel comprises an Op-Amp 913, a current amplifier 912, and coil pair 902, 904. The Z-axis channel comprises an Op-Amp 915, a current amplifier 914, and coil pair 905, 906. As shown, each pair of coils is connected in series and further connected to the output of power amplifiers, 910, 912, and 914, for the X, Y and Z axes, respectively. The alternative architecture to FIG. 1 shown in FIG. 13C receives its input signal command from the joystick, 900. Upon command from the operator using the joystick 900 to move in one or more axes, the joystick 900 sends its signal to an array of operational amplifiers, 911, 913, and 915, corresponding to the X, Y, and the Z axes respectively. Op-Amps 911, 913, and 915 translate the signal received from joystick 900 and perform an Inverse operation on the matrix of the three signals for the three axes. The Op-Amp array 932 multiplies the signal from joystick 900 represented as vector **V**, 923, by another matrix **M**-inverse, shown in FIG. 13F and 13G as 927, such that the output of the Op-Amp array 932 is **M**-inverse times **V**, where **M** is the characteristic matrix 925 of the cluster arrangement comprising the six coils 901 through 906. The output from the Op-Amp array 932, comprising Op-Amps 911, 913, and 915, is obtained, and is fed to power amplifiers 910, 912, and 914, driving the six coils 901 through 906 to obtain the result of generating a motion in the desired direction, hence providing the apparatus 501 with the ability to translate the desired motion of the operator or the clinician as to move the catheter tip 377 in a body lumen of a patient, 390. This scheme as shown in FIG. 13D, 13E, 13F,

and 13G, is reduced further in FIG. 13H where the input signal **V**, 931, from Joystick 900, is fed to an Mchar-Inverse Op-Amp array, 932. The resultant output from the array 932 is the matrix product Mchar-Inverse by the vector **V**. This signal is fed to current amplifiers 928, their signal output represented by the vector **B**, 933, is then fed as the respective current to the coils 901 through 906, thereby producing the result of translating the hand-movement of the clinician into the appropriate signal, thus moving the catheter tip to the desired location.

Please amend paragraph [0130] as follows:

FIG. 14 shows an arrangement of the magnetic field sensors and temperature sensor pairs into sensor arrays 306, 307, 308, 309, 311, 312, 313, 314, 316, 317, 318, and 319. Each orthogonal axis is divided into two poles by positioning a second electromagnet coaxially with the first. For example, electromagnet ~~132x~~ 132X is coaxial with electromagnet ~~138x~~ 138X, electromagnet ~~132y~~ 132Y is coaxial with electromagnet ~~138y~~ 138Y, and electromagnet ~~132z~~ 132Z is coaxial with electromagnet ~~138z~~ 138Z. Since the rotational movements of the virtual tip 405 defined by θ 403 and EL 404, as shown in FIG. 6 occur within the X-Y plane and the X-Z plane respectively, electromagnet poles along the X-, Y- and Z- axes are sufficient to affect movement of the present catheter tip 377 in exactly the same five axes as defined for the virtual tip 405 as previously described in connection with FIG. 6.

Please amend paragraph [0131] as follows:

In one embodiment, each magnetic field sensor contained in the MFS arrays 307, 308, 312, 313, 317, and ~~319~~ 318, is paired with a temperature sensor (TS) contained in temperature sensor arrays 306, 309, 311, 314, 316, and ~~318~~ 319. These paired combinations are detailed in FIG. 14 and in the table below. The magnetic field sensors-temperature sensor (MFS/T) pairs are arranged in quadrants on the pole face of the electromagnets ~~132x~~ 132X, ~~132y~~ 132Y, ~~132z~~ 132Z, ~~138x~~ 138X, ~~138y~~ 138Y, and ~~138z~~ 138Z.

Please amend paragraph [0132] as follows:

As shown in FIG. 13, the MFS/TS pairs 350, 351, 352, and 353 are arranged in quadrants on electromagnet ~~132x~~ **132X** pole face. Magnetic field sensor and temperature sensor (TS) pairs 354, 355, 356, and 357 are arranged in quadrants on electromagnet ~~138x~~ **138X** pole face. Magnetic field sensor and temperature sensor (TS) pairs 358, 359, 360, and 361 are arranged in quadrants on electromagnet ~~132y~~ **132Y** pole face. Magnetic field sensor and temperature sensor (TS) pairs 362, 363, 364, and 365 are arranged in quadrants on electromagnet ~~138y~~ **138Y** pole face. Magnetic field sensor and temperature sensor (TS) pairs 366, 367, 368, and 369 are arranged in quadrants on electromagnet ~~132z~~ **132Z** pole face. Magnetic field sensor and temperature sensor (TS) pairs 370, 371, 372, and 373 are arranged in quadrants on electromagnet ~~138z~~ **138Z** pole face.

Please amend paragraph [0133] as follows:

FIG. 14 illustrates the pairing of the magnetic field sensors and temperature sensors as mounted in FIG. 13. The magnetic field sensors and temperature sensors are mounted as isothermal pairs, and each pair functions in conjunction with each other. The magnetic field sensors measure the position of the present tip 377 during the measurement phase, as controlled by microcontrollers ~~102x~~ **102X**, ~~102y~~ **102Y** and ~~102z~~ **102Z** of XCA 305, YCA 310 and ZCA 315, respectively, during which time the electromagnets 132X, 132Y, 132Z, 138X, 138Y, and 138Z are de-energized. This is done in order to be able to take accurate and sensitive measurements with the magnetic field sensor arrays 307, 308, 312, 313, 317, and 318, as they would otherwise be saturated with the flux from the electromagnets. The temperature sensor arrays 306, 309, 311, 314, 316, and 319 monitor the ambient temperature to detect an increase that may be uncomfortable for the patient or potentially damaging to surrounding tissues, and provide correctional data for calculating position based on the magnetic field sensors. The isothermal pairs are as follows:

Please amend paragraph [0134] as follows:

~~**magnetic**~~ **Magnetic** field sensor 113X and temperature sensor (TS) ~~**122x**~~ **122X** form pair 350. Magnetic field sensor ~~**114x**~~ **114X** and temperature sensor (TS) ~~**123x**~~ **123X** form pair 351. Magnetic field sensor ~~**115x**~~ **115X** and temperature sensor (TS) ~~**124x**~~ **124X** form pair 352. Magnetic field sensor ~~**116x**~~ **116X** and temperature sensor (TS) ~~**125x**~~ **125X** form pair 353.Magnetic field sensor ~~**117x**~~ **117X** and temperature sensor (TS) 126X form pair 354. Magnetic field sensor ~~**118x**~~ **118X** and temperature sensor (TS) ~~**127x**~~ **127X** form pair 355. Magnetic field sensor ~~**119x**~~ **119X** and temperature sensor (TS) ~~**128x**~~ **128X** form pair 356. Magnetic field sensor ~~**120x**~~ **120X** and temperature sensor (TS) ~~**129x**~~ **129X** form pair 357. Magnetic field sensor ~~**113y**~~ **113Y** and temperature sensor (TS) ~~**122y**~~ **122Y** form pair 358. Magnetic field sensor ~~**114y**~~ **114Y** and temperature sensor (TS) ~~**123y**~~ **123Y** form pair 359. Magnetic field sensor ~~**115y**~~ **115Y** and temperature sensor (TS) ~~**124y**~~ **124Y** form pair 360. Magnetic field sensor ~~**116y**~~ **116Y** and temperature sensor (TS) ~~**125y**~~ **125Y** form pair 361. Magnetic field sensor ~~**117y**~~ **117Y** and temperature sensor (TS) ~~**126y**~~ **126Y** form pair 362. Magnetic field sensor ~~**118y**~~ **118Y** and temperature sensor (TS) ~~**127y**~~ **127Y** form pair 363. Magnetic field sensor ~~**119y**~~ **119Y** and temperature sensor (TS) ~~**128y**~~ **128Y** form pair 364. Magnetic field sensor ~~**120y**~~ **120Y** and temperature sensor (TS) ~~**129y**~~ **129Y** form pair 365. Magnetic field sensor ~~**113z**~~ **113Z** and temperature sensor (TS) ~~**122z**~~ **122Z** form pair 366. Magnetic field sensor ~~**114z**~~ **114Z** and temperature sensor (TS) ~~**123z**~~ **123Z** form pair 367. Magnetic field sensor ~~**115z**~~ **115Z** and temperature sensor (TS) ~~**124z**~~ **124Z** form pair 368. Magnetic field sensor ~~**116z**~~ **116Z** and temperature sensor (TS) ~~**125z**~~ **125Z** form pair 369. Magnetic field sensor ~~**117z**~~ **117Z** and temperature sensor (TS) ~~**126z**~~ **126Z** form pair 370. Magnetic field sensor ~~**118z**~~ **118Z** and temperature sensor (TS) ~~**127z**~~ **127Z** form pair 371. Magnetic field sensor ~~**119z**~~ **119Z** and temperature sensor (TS) ~~**128z**~~ **128Z** form pair 372. Magnetic field sensor ~~**120z**~~ **120Z** and temperature sensor (TS) ~~**128z**~~ **128Z** form pair 373.

Please amend paragraph [0141] as follows:

FIG. 16 illustrates a bi-plane x-ray ring incorporating the apparatus of FIG. 1B. Figures 16A, 16B and 16C are further elaboration of FIG. 16, and show in further detail, elements that could not be depicted by the isometric view of FIG. 16, or were omitted from FIG. 16 for clarity.

Additionally, Figs. 16A, 16B, and 16C are top, end, and side views respectively of the **~~electromagnet and imaging~~** **polar** assembly 391 and support assembly 385.

Please amend paragraph [0144] as follows:

The trunnion 388 is centered on an axis, namely the T-axis 387 depicted in FIG. 16A. The T-axis encoder 394 is mechanically coupled to the trunnion 388 to encode positional data of the support assembly 385 in the T-axis. A gimbal-axis (G-axis) 386, depicted in FIG. 16A, intersects with the T-axis **~~378~~** **387** at the center point of the polar support 391. This center point coincides exactly with the center point of the X-ray field of view. A G-axis encoder 393 is mechanically coupled to the support assembly 385 along the G-axis 386. A detailed description of the functionality of the above components will follow in the ensuing description.

Please amend paragraph [0148] as follows:

Figure 17B illustrates the implantation of cardiac pacemaker 801 with electrodes as shown, placed in area relative to the S.A. Node 802, A.V. Node 803, and a bundle of His 804. Further illustrated are the right and left bundle branches 805. Pacemaker implantation is essential for the survival of patients with heart rhythm or electrical conduction disturbances. This procedure is performed by the implantation of a small electrode in the heart cavity wall (ventricle or atrium). The other end of the electrode is attached to an electronic device 801 which is implanted under the chest skin and which generates stimulation pulses to simulate the heart rhythm. Similar devices apply electrical shock when life threatening heart electrical disturbances are detected by the electrodes (Automatic Implantable Cardiac Defibrillator (AICD). These electrodes are placed through a vein by pushing and manipulating under fluoroscopy. Through the use of the apparatus proposed GCI 501 and guidewire 379 fitted with magnetic tip 381 is used to carry and place the electrodes of pacemaker 801 in its proper position by using the method and apparatus described in this patent. By employing the fiduciary markers 700A1, 700A2, 700A3, 700A4, 700B1, 700B2, 700B3, and 700B4 the physician navigates the guidewire 379 through the heart lumen while having a continuous dynamic referential frame identifying the guidewire tip 381 and as shown in **figure** 17 and further illustrated by figure 17A. Many times, the manipulation to place the electrodes in a proper position is difficult and the results are sub-

optimal due to anatomical variations. The use of the proposed apparatus 501 provides simplicity in performing such a complex operation while the physician is capable of moving, pushing, and placing the electrodes of pacemaker 801 in its precise anatomical position without compromise due to the inability of navigating, guiding, controlling, and imaging the movement of the guidewire and the pacemaker electrodes accurately.

Please amend paragraph [0154] as follows:

During calibration, Calibration Fixture (CF) 321 is placed within the polar configuration 374 and connected to Virtual Tip/Calibration Fixture Controller (VT/CFC) 303. Virtual Tip/Calibration Fixture Controller (VT/CFC) 303 then moves Calibration Fixture (CF) 321 by sending codes to drive stepper motors ~~55c~~ 55c, ~~57c~~ 57C, ~~59c~~ 59C, ~~61c~~ 61C, and ~~63c~~ 63C. Encoders ~~64c~~ 64C, ~~66c~~ 66C, ~~68c~~ 68C, ~~70c~~ 70C, and ~~72c~~ 72C are then read by Calibration Fixture (CF) 321 to determine the present position and orientation of magnet 411. The position data from the encoders is compared to the position data derived from magnetic field sensor arrays 307, 308, 312, 313, 317, and 318 (Figs. 1, 7, 8, and 9). The magnetic field sensor arrays 307, 308, 312, 313, 317 and 318 responses are thus characterized for the full range of the magnet 411 positions and orientations, and hence for the magnetic catheter tip 377 as well.

Please amend paragraph [0156] as follows:

The electromagnetic field generated by electromagnets ~~132x~~ 132X, ~~132y~~ 132Y, ~~132z~~ 132Z, ~~138x~~ 138X, ~~138y~~ 138Y, and ~~138z~~ 138Z of FIG. 13 will produce a resultant force on the present catheter assembly tip 377 and guidewire assembly tip 381 (Figs. 15 and 15A). This resultant force can be represented by force vector B 600 with a given magnitude and direction. This resultant force vector B together with its constituent vectors are illustrated in FIG. 18. Vector B is the resultant vector of the force vectors emanating from the six electromagnets ~~132x~~ 132X, ~~132y~~ 132Y, ~~132z~~ 132Z, ~~138x~~ 138X, ~~138y~~ 138Y, and ~~138z~~ 138Z together, upon a move command from the XCA 305, YCA 310 and ZCA 315. Vector Bx 601 is the projection of Vector B 600 on the X-axis, Vector By 602 is the projection of Vector B 600 on the Y-axis, and Vector

Bz 603 is the projection of vector B 600 on the Z-axis. The angles α 604, β 605, and δ 606 are the corresponding angles between the vectors B 600 and Bx 601, vectors B 600 and By 602, and vectors B 600 and Bz 603, respectively.

Please amend paragraph [0158] as follows:

The force vector B is produced through commands sent from system controller 102 based on: 1) inputs from sensor arrays 307, 308, 312, 313, 317, and 318 processed by XCA ~~**301**~~ **305**, YCA 310 and ZCA 315 on the location of the present catheter tip 377 within the patient's body 390, and 2) inputs from VT/CFC 303 on the desired position of the present catheter tip 377 as indicated by virtual tip 405 position. A code stored in ROM 40 of system controller 302 (FIG. 3) is processed by microcontroller 33 to generate the constituent vector components Bx 601, By 602, and Bz 603 of B 600. The magnitude of each of these constituent vectors will be translated to the appropriate XCA 305, YCA 310, and ZCA 315 to cause changes in modulator outputs, which, in turn, change the electromagnetic field produced by electromagnets ~~**132x**~~ **132X** and ~~**138x**~~ **138X**, ~~**132y**~~ **132Y** and ~~**138y**~~ **138Y**, and ~~**132z**~~ **132Z** and ~~**138z**~~ **138Z**. The constituent vectors Bx, By and Bz will then be physically realized as electromagnetic fluxes along the X-, Y-and Z-axes and thereby produce a resultant force B 600 on the present catheter tip 377 to effectively drag it to the desired position.

Please amend paragraph [0161] as follows:

~~The electromagnetic field induced by electromagnets 132x, 132y, 132z, 138x, 138y, and 138z of FIG. 13 produces a resultant force on the present catheter assembly tip 377 and guidewire assembly tip 381 (Figs. 15 and 15A). This resultant force can be characterized as a force vector with a given magnitude and direction, and is illustrated in FIG. 18 along with its constituent vectors. Vector B 600 is the resultant vector of the force vectors emanating from the six electromagnets 132x, 132y, 132z, 138x, 138y, and 138z together, upon a move command from the XCA 305, YCA 310 and ZCA 315. Vector Bx 601 is the projection of Vector B on the X-axis, Vector By 602 is the projection of Vector B on the Y-axis, and Vector Bz 603 is the~~

~~projection of vector B on the Z-axis. The angles α 604, β 605, and δ 606, are the corresponding angles between the vectors B and Bx, vectors B and By, and vectors B and Bz, respectively.~~

Please amend paragraph [0162] as follows:

FIG. 18A illustrates one embodiment of a magnetic catheter tip 607. This magnetic tip 607 corresponds to the combination of the responsive tip 377 of the catheter assembly 375 and the responsive tip 381 of the guidewire assembly 379 (Figs. 15 and 15A). The magnetic tip 607 is represented by its two poles a_N, 607A and a_S 607B in connection with a Virtual Origin 608. The Virtual Origin 608 is defined by the center of travel of the Virtual Tip (VT) 405 in the X-, Y-, and Z- axes 400, 401 and 402 (FIG. 6). The Virtual Origin 608 also coincides with the center of the travel of the calibration magnet 411 in the X-, Y-, and Z- axes 406, 407 and 408, during calibration (FIG. 12). The assumption is that the Virtual Origin 608 is in the center of the x-ray field of view, as well as the center of the ~~**sagnetic**~~ **magnetic** field sensors (MFS) sensing volume and the center of the electromagnet (EM) control volume. The Virtual Origin 608 also coincides with the center of travel of the Calibration Fixture (CF) in the X, Y, and Z axes, during calibration.

Please amend paragraph [0163] as follows:

FIG. 18B illustrates the resultant position vector An 609 that defines the position of the catheter tip 607 as detected by the magnetic field sensor arrays 307, 308, 312, 313, 317, and 318 and computed by microcontrollers ~~**102x**~~ **102X**, ~~**102y**~~ **102Y** and ~~**102z**~~ **102Z** of XCA 305, YCA 310 and ZCA 315. The constituent vectors Xn, Yn, and Zn are the projections of the position vector An on the X-axis, Y-axis and Z-axis, respectively. The angles α 609A, β 609B, and γ 609C, are the projected angles of the vector A_N on the X, Y, and Z axes, respectively. This orthogonal representation corresponds to the polar configuration 374 of FIG. 16.

Please amend paragraph [0166] as follows:

FIG. 19A illustrates a distance d 617 between two adjacent X-axis magnetic field sensors~~,~~ ~~Magnetic field sensors X1 and X2 618 and 619 respectively~~: $-X_1$ 618 and $-X_2$ 619. Also shown in FIG. 19A are two additional magnetic field sensors, -X3 and –X4. The magnetic field sensors $–X_1$, $-X_2$, $-X_3$, $-X_4$ are the MFS and the temperature sensor (TS) pairs, corresponding to 354, 355,

356, and 357, respectively, and X_1, X_2, X_3, and X_4 are the MFS and TS pairs corresponding to 350, 351, 352, and 353, respectively.

Please amend paragraph [0185] as follows:

To illustrate how system controller 302 determines the position of the present catheter tip, the calculations used by microprocessor ~~102x~~ 102X of XCA 305 with respect to the X-axis and the virtual origin 608 will now be described, with the understanding that microprocessors 102y of YCA 310 and 102z of ZCA 315 will perform similar calculations, with each generating positional data concerning the Y- and Z- axes, respectively.

Please amend paragraph [0187] as follows:

Each MFS/TS pair 354, 355, 356, 357 mounted on the polar face of electromagnet ~~138x~~ 138X will provide location data to microprocessor ~~102x~~ 102X of XCA 305. The measured distance to a_N 607A, for example, from MFS/TS pair 354 will be referred to as $(-x_1)$; the distance measured by MFS/TS pair 355 will be referred to as $(-x_2)$; the distance measured by MFS/TS pair 356 will be referred to as $(-x_3)$; the distance measured by MFS/TS pair 357 will be referred to as $(-x_4)$.

Please amend paragraph [0188] as follows:

Likewise, each MFS/TS pair 350, 351, 352, 353 mounted on the polar face of electromagnet ~~132x~~ 132X will provide location data to microprocessor ~~102x~~ 102X of XCA 305. The measured distance of a_N 607A from MFS/TS pair 350 will be referred to as $(+x_1)$; the distance measured by MFS/TS pair 351 will be referred to as $(+x_2)$; the distance measured by MFS/TS pair 352 will be referred to as $(+x_3)$; the distance measured by MFS/TS pair 353 will be referred to as $(+x_4)$.

Please amend paragraph [0192] as follows:

The numerical solution, is graphically shown in Figure 20A is achieved by using the canonical formalism described below. It should be noted that this numerical solution is performed in for example in a background mode by microprocessor ~~102x~~ **102X** of XCA 305 and similarly for y axis and z axis.

$$hx_1x_2 = \frac{x_1x_2\sin(\theta x_1x_2)}{d}$$

$$Bx_1x_2 = \sqrt{x_1^{\ 2} - hx_1x_2^{\ 2}}$$

$$\theta x_2x_3 = \cos^{-1}\left(\frac{d^2 - x_2^{\ 2} - x_3^{\ 2}}{2x_2x_3}\right)$$

$$Ax_2x_3 = \frac{x_2x_3Sin(\theta x_2x_3)}{d}$$

$$Bx_2x_3 = \sqrt{x_2^{\ 2} - hx_2x_3}$$

$$P_Bx_1 = \sqrt{Bx_1x_2^{\ 2} + Bx_2x_3^{\ 2}}$$

$$Ax_1x_2 = \sqrt{x_1^{\ 2} - P_Bx_1^{\ 2}}$$

The angles of θx_2x_3, θx_3x_4, and θx_1x_4 are calculated in a similar way.

Please amend paragraph [0194] as follows:

Likewise, the distance from the polar face ~~132x~~ **132X** to the point a_N is determined as follows:

$$+x = \left(\frac{x_1x_2A + x_2x_3A + x_3x_4A + x_4x_1A}{4}\right).$$

Please amend paragraph [0196] as follows:

The distance of a_N from the virtual origin 608 is determined since the virtual origin is the common point of reference between the VT assembly 304 and the calibration fixture (CF) 321. These distances are given for the three axes by the following sets of equations, where X_D 616 is the distance between two coaxial electromagnets ~~132x~~ **132X** and ~~138x~~ **138X** (refer to FIG. 19),

Y_D is the distance between two coaxial electromagnets ~~132y~~ 132Y and ~~138y~~ 138Y, and Z_D is the distance between two coaxial electromagnets ~~132z~~ 132Z and ~~138z~~ 138Z:

$$\frac{X_D}{2}+(-X)$$

$$\frac{X_D}{2}+(+X)$$

where:

$$\left(\frac{X_D}{2}+(-X)\right)+\left(\frac{X_D}{2}+(-X)\right)=X_D$$

$$Zc=\frac{Zn-Zs}{2}$$

Please amend paragraph [0199] as follows:

Using these results, system controller 302 can compare the present catheter tip 377 location to the desired tip location. FIG. 23 illustrates a logical computational flow taken by the system controller (SC) 302 in determining the position of the present tip 377, using the following mathematical relations:

1. System Controller (SC) 302 inhibits X-axis controller and amplifier (XCA) 305, Y-axis controller and amplifier (YCA) 310, and Z- axis controller and amplifier (ZCA) 315 modulator outputs.
2. X-axis controller and amplifier (XCA) 305, Y-axis controller and amplifier (YCA) 310, and Z- axis controller and amplifier (ZCA) 315 read the magnetic field sensor array 307, 308, 312, 313, 317, and 318 outputs.
3. X-axis controller and amplifier (XCA) 305, Y-axis controller and amplifier (YCA) 310, and Z-axis controller and amplifier (ZCA) 315 read temperature sensor (TS) array 306, 309, 311, 314, 316, and 319 outputs.
4. X-axis controller and amplifier (XCA) 305, Y-axis controller and amplifier (YCA) 310, and Z-axis controller and amplifier (ZCA) 315 apply digital temperature compensation to the outputs of the magnetic field

sensor arrays 307, 308, 312, 313, 317, and 318 by referring to correction data (typically stored in Non Volatile Memory 105x, 105y, and 105z).

5. System Controller (SC) 302 inputs the corrected magnetic field sensor data from X-axis controller and amplifier (XCA) 305, Y-axis controller and amplifier (YCA) 310, and Z-axis controller and amplifier (ZCA) 315, and interpolates a 5-axis data set from the three orthogonal components (Bx, By, Bz) of the magnetic field produced by the present tip. The tip position is calculated using the following two relations:

a) The magnitude of the force vector B 600 is given by the equation:

$$B = \sqrt{Bx^2 + By^2 + Bz^2}$$; and

b) the direction of the force vector B is given by the three resultant angles, as:

$$\alpha = \frac{\cos^{-1} Bx}{B}, \quad \beta = \frac{\cos^{-1} By}{B}, \quad \delta = \frac{\cos^{-1} Bz}{B}$$

6. System Controller (SC) 302 inputs the cardio position (CP) from the auxiliary equipment (x-ray, ultrasound, etc) 322 via Communication Controller (CC) 320. The cardio position (CP) data set is dynamic due to the beating of the heart.

7. System Controller (SC) 302 calculates the present position (AP) by combining the cardio position (CP) and the HP data sets.

8. System Controller (SC) 302 inputs Virtual Tip 405 position data from Virtual Tip/Calibration Fixture Controller (VT/CFC) 303.

9. System Controller (SC) 302 calculates the DP by combining the cardio position (CP) data set with that of the Virtual Tip (VT).

10. System Controller (SC) 302 then determines the position error (PE) by comparing the DP with the AP.

11. If the position error PE is less than an error threshold value, then the System Controller (SC) 302 enables X-axis controller and amplifier (XCA) 305, Y-axis controller and amplifier (YCA) 310 and Z-axis

controller and amplifier (ZCA) 315 ~~with the~~ continues to use the same modulation and polarity.

12. If the position error PE is greater than the error threshold value, then the System Controller SC 302 alters the duty cycle and/or polarity of the modulation inputs to XCA 305, YCA 310, and ZCA 315 accordingly.